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ABSTRACT

A study of 55 growth-disturbed children, aged 8-17, was conducted to assess how rate of physical maturation and pubertal development influences cognitive and neuropsychological functioning. The sample included 27 boys with short stature and delayed pubertal development (SSB), 15 girls with delayed puberty (DPG), and 13 girls with precocious puberty (PPG). Results demonstrated a clear maturation rate effect, which reflected primarily the timing of puberty. SSB and DPG outperformed PPG on spatial tasks, while PPG outperformed SSB and DPG on verbal tasks. SSB were also more strongly lateralized than PPG on tasks of hemispheric specialization, especially those tapping right hemisphere functioning. Results for experimental cognitive tasks showed that SSB encoded visual stimuli faster than other groups, but had more difficulty comprehending complex visual information and naming objects and had smaller memory span sizes. Regression analyses predicting performance from biomaturational variables indicated that rate of pubertal development was the primary predictor of intellectual functioning and hemispheric lateralization; advanced puberty correlated positively with verbal ability and negatively with left hemisphere specialization and spatial ability. Hormonal levels which were correlated with aspects of cognitive functioning indicated that the development of different abilities may be under the control of different hormonal systems. (60 references) (Author/JDD)

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# Cognitive Function in Individuals with Atypical Pubertal Development

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## Abstract

A study of 55 growth-disturbed children was conducted to assess how rate of physical maturation and pubertal development influences cognitive and neuropsychological functioning. The sample included 27 boys with short stature and delayed pubertal development (SSB), 15 girls with delayed puberty (DPG), and 13 girls with precocious puberty (PPG). Results demonstrated a clear maturation rate effect, consistent with Waber's 1976 study. This reflected primarily the timing of puberty. SSB and DPG outperformed PPG on spatial tasks, while PPG outperformed SSB and DPG on verbal tasks. SSB were also more strongly lateralized than PPG on tasks of hemispheric specialization, especially those tapping right hemisphere functioning. Results for experimental cognitive tasks showed that SSB encoded visual stimuli faster than other groups, but had more difficulty comprehending complex visual information, naming objects, and smaller memory span sizes. Regression analyses predicting performance from biomaturational variables indicated that rate of pubertal development was the primary predictor of intellectual functioning and hemispheric lateralization; advanced puberty correlated positively with verbal ability and negatively with left hemisphere specialization and spatial ability. Hormonal levels which were correlated with aspects of cognitive functioning indicated that the development of different abilities may be under the control of different hormonal systems.

# Cognitive Function in Individuals with Atypical Pubertal Development

Although psychologists have been studying the relationships between mental and physical development for many years (eg. Porter, 1895 and Crompton, 1907, as cited by Abernathy, 1936; Shuttleworth, 1939, Simmons, 1944; Duke et al, 1982 Jones & Bayley, 1950; Peskin, 1973), it was only recently that the concept 'rate of maturation' has been used as a tool for examining the mechanisms underlying individual and sex-related differences in cognitive functioning. Because different patterns of ability are observed among persons who mature at different rates, it is thought that maturation (or its implicit physiological correlates) may play an important role in the organization of higher cortical functions. This is best exemplified in a study by Deborah Waber (1976, 1977) in which she demonstrated that regardless of sex, children who matured more slowly (as measured by pubertal status) had better spatial than verbal ability than children who matured rapidly, who tended to show the reverse ability pattern. Because she also found that late maturers were more strongly lateralized than early maturers on tasks of hemispheric specification, she proposed that differences in rates of physical maturation would affect hemispheric organization, and this in turn would lead to differences in specific ability levels.

Since Waber's original paper in 1976, there have been a number of attempts at replicating her work, including several by Waber herself (Waber, Bauermeister, Cohen, Ferber & Wolff, 1981; Waber, Mann, Merola & Moylan, 1985), but with generally less success. Although these studies have

demonstrated maturation rate effects for specific abilities (Herbst & Petersen, 1980; Newcombe & Bandura, 1983), laterality (Rovet, 1983), or both (Waber et al, 1981), the relationship appears to be more complex than originally conceived (see Newcombe and Dubas, 1985, for a review and meta-analysis). Factors such as SES (Waber et al, 1981), age (Waber, 1977), sex (Rovet, 1981), pubertal status (Diamond et al, 1955; Galatzer and Gordon, 1982; Waber et al, 1985), pubertal timing (Meyer-Bahlburg, Bruder, Feldman, Ehrhart, Healey & Bell, 1985), and hormone levels (Gordon and Lee, 1986; Waber et al, 1985) have also been found to influence the relationship. For example, Waber et al (1981) reported that the effects of physical maturity on abilities differed depending on the child's social class standing: visuospatial processing was positively associated with physical maturity in upper middle class children, as found previously (Waber, 1976), but in children from middle and lower classes, motor sequencing was related to physical maturity and sequencing to neuromotor status, respectively. In reconsidering her maturational hypothesis, Waber has suggested that experience provides the context through which maturation mediates behaviour (Waber et al, 1985).

One of the major problems with this line of research concerns the use of pubertal indices as markers for rate of physical maturation, the assumption being that the timing of puberty reflects a life-long growth rate laid down in the central nervous system early in life. First, there are the many behavioural and emotional problems associated with puberty itself, which might interact with performance. In addition, there may also be sex-related disruptions in hemispheric functioning that affect how complex visuospatial material is processed. For example, Carey and Diamond (1980) found that girls

who were in the midst of pubertal change performed more poorly on face encoding tasks; this effect disappeared once past puberty.

Two studies have recently attempted to control for pubertal state effects by examining subjects before or after puberty. Newcombe, Dubas and Moore (1985) correlated age at menarche with performance on spatial tasks in postmenarcheal undergraduate women (thereby controlling for pubertal state), but failed to find an effect of pubertal timing (see also Strauss & Kinsbourne, 1981). Waber et al (1985) assessed children who then were followed prospectively into puberty to ascertain whether they would be early or late maturers. They, too, failed to find a maturation rate effect. Children who subsequently entered puberty early did not differ from those who entered it later when assessed while still pre-pubertal. These findings therefore suggest that relative pubertal status at the time of testing is an important contributor to individual differences in specific ability levels. Waber et al (1985) found in addition a more subtle influence of maturation rate, affecting discrete components of cognitive functioning, rather than more generalized intellectual abilities as observed previously. Early and late maturers appeared to be using different approaches for dealing with serial recall, phonemic encoding, and complex visuospatial and visuomotor tasks when tested during their puberty.

Another problem characterizing this research is the use of a single laterality task to mark total hemispheric organization. In fact, a major criticism of Waber's original study was her use of a task of left hemisphere specialization to explain the maturational effects on spatial processing (Newcombe & Bandura, 1983), when spatial processing involves the right

hemisphere to a greater degree than the left (Kimura, 1967). This is important because if maturational phenomena are to mediate specific abilities by altering patterns of hemispheric organization, it is necessary to show that maturation rate and hemispheric organization, are themselves linked. However, when Newcombe and Bandura (1983) attempted to circumvent this by using a task of right hemisphere specialization, they found neither spatial ability nor pubertal timing were related to right hemisphere functioning. No study has as yet attempted to examine both right and left hemisphere cerebral asymmetries.

Over the past decade, we have been exploring the maturation issue in both prepubertal and pubertal children with clinically defined abnormalities in physical maturation (Netley & Rovet, in press). In one study, children with ideopathic precocious or delayed puberty were compared with matched normal controls (Rovet, 1983). Results of tasks of verbal and spatial ability, and hemispheric lateralization (reflecting left hemisphere specialization) provided little support for the Waber hypothesis. Rather than observing a verbal advantage in children with precocious puberty or a spatial advantage in children with delayed, I found that children with atypical pubertal development failed to show the usual sex-related difference in cognitive abilities (males superior in spatial ability, females superior in verbal ability) observed with the controls. Both males and females with precocious puberty scored lower than controls in verbal ability while boys with precocious puberty also scored lower in spatial ability; girls with delayed puberty scored lower in both verbal and spatial areas while boys with delayed puberty showed a slight verbal advantage. Unfortunately, this study too failed to differentiate between maturation rate and pubertal state phenomena.

Several years ago, we had the opportunity to examine another series of children with atypical pubertal onset who were being seen in the Growth Clinic at the Hospital for Sick Children for their abnormal developmental status. They included a group of boys with short stature and delayed pubertal onset (SSB); girls with normal stature but delayed pubertal onset (DPG); and girls with precocious puberty (PPG). The major objectives of this investigation were: (i) to compare patterns of intellectual ability in the three groups of children; (ii) to investigate their hemispheric organization using tasks of both left and right hemisphere specialization; (iii) to examine individual cognitive processes; and (iv) to identify the biological factors contributing to differences in ability, brain organization, and cognitive processing. The biological factors included measures of physical growth and development (both current and in fetal life), pubertal status (both state and timing), and hormones. Because our comparisons required correlating psychological indices with both non-intrusive (height, weight) and intrusive physical measurements (radiological state, Tanner stage, hormonal assays), there were no normal controls. If Waber's original hypothesis held, we predicted that (a) SSB and DPG would outperform PPG on spatial tasks whereas PPG would outperform SSB and DPG on verbal, (b) that PPG would be less lateralized than SSB and DPG, and (c) that hemispheric specialization would predict differences in levels of specific ability. In accordance with Waber's more recent findings (Waber et al, 1985), we also predicted (d) that the three groups would differ systematically in the way they processed information on experimental cognitive tasks.

## METHOD

### Subjects

The sample consisted of 27 growth-delayed (mean age = 13.9 ± 1.1, range 11.0 to 17.0), 15 growth-delayed girls (mean age = 12.6 ± 2.2, range 10.0 to 16.6), and 13 growth-advanced girls, (mean age = 8.5 ± 1.5, range 6.3 to 11.7). The criteria for inclusion in the growth-delayed group were: (i) height greater than 2 SD below the mean for age; delayed puberty and/or significantly retarded skeletal maturation; no indication of familial short stature; age greater than eleven years in boys; (ii) significantly delayed pubertal onset or delayed bone age with short stature; age above ten years in girls. Criteria for inclusion in the growth-advanced group were evidence of breast, pubic hair development, or menses, before age eight in girls and pubic hair before age 10 in boys. The criteria for inclusion in this study were different for boys than for girls, given that both the reasons for bringing them to clinic and the prevalence of each condition differ by sex. For example, precocious puberty is four times more common in girls than boys (Money & Meredith, 1967), whereas ideopathic short stature is more common in boys than girls (Reindollar, Byrd & McDonough, 1981). Regarding growth delayed children, parents of boys appear to be more concerned about the height issue, whereas parents of girls appear to be more concerned about sexual maturation. The children who participated represented all cases fitting our criteria who had been seen in the hospital's growth clinic over a one year period and had agreed to the study. The growth-delayed children represented about 75% of all eligible cases, whereas, the growth-advanced girls

represented only about 50%. Although three boys with precocious puberty were seen in the clinic in the one year period, because only one was allowed to participate, no boys with precocious puberty were presently included.

The majority of growth-delayed boys were diagnosed as having constitutional short stature, whereas the majority of growth-delayed girls had ideopathic delayed puberty. At the time of testing, 16 of the boys and 6 of the girls were pubertal. Nine of the 26 boys had received medication (testosterone) for their growth problem, with six of the nine having completed their course of therapy by the time of testing. Four girls with DPG had been treated with androgens or estrogens (depending on their situation), three of whom were still receiving medication when tested.

The 13 girls with advanced maturation all had idiopathic precocious puberty. Their mean age of pubertal onset was 6.26 years (range 1.3 to 8.0 years). Three were on hormonal therapy, two with depo-Provera and one with buserilin.

## Measures and Tests

### Biomaturational Measures

Physical growth. There were three indices of physical growth: height, weight, and skeletal maturation as measured by the bone age equivalent of the child's knee or wrist according to the standards of Greulich and Pyle (1959) at the time of testing. Heights and weights were first converted to percentiles using the Tanner growth charts (Tanner, Whiteside & Takaishi, 1966) and then percentile ratings were converted to standard scores. This

provided a relatively more extended distribution, given that the majority of growth delayed boys were below the first percentile in height. Bone age equivalents were converted to an index of relative maturational status (BQ) by subtracting bone age (in months) from chronological age (CA) and dividing by CA.

Prenatal growth rate. A set of dermatoglyphic recordings were taken for each child and the total finger ridge count (TFRC) was determined. Because the number of ridges in the finger pad set down early in fetal life (Holt, 1968) appear to reflect the rate of somatic maturation in utero (Mittwoch, 1973; Polani, 1981; Penrose, 1967), this is thought to provide a retrospective measure of fetal growth rate (Netley & Rovet, 1983).

Pubertal Development. Tanner staging of breast and pubic hair development were available for all girls at or near the time of assessment, while Tanner staging of pubic hair development, stretch penile length, and testicular volume were available for each boy. Each measure was converted to a pubertal age using the Tanner growth charts for breast, pubic hair, and testicular development. The tables of Schonfeld and Beebe (1942) were used for the age conversion of penile length. A mean pubertal age was determined for each child by computing the average pubertal age across indices. For children younger than their projected pubertal age by this method, we used their mean bone age, and penile age (boys only) as an equivalent, given that bone age is highly correlated with pubertal status (Duke et al, 1982). A pubertal quotient (PQ) was obtained by subtracting chronological age (CA) from pubertal age and dividing by CA. Children with advanced pubertal development had positive PQ scores while children with delayed pubertal development had

negative PQ scores. The mean (SD) PQ scores were -.144 (.125) for SSB, -.134 (.071) for DPG and .325 (.291) for PPG.

Hormones. Hormonal data at or near the time of testing were available for nine of the growth-delayed boys, nine of the growth-advanced girls and none of the growth-delayed girls. The reason for requesting these measurements appeared to be the discretion of the staff physician and did not appear to us to be associated with any particular problem or condition. For SSB, luteinizing hormone (LH), follicular stimulating hormone (FSH), testosterone and androstenedione (N=3) levels were obtained; for PPG, LH, FSH, testosterone, androstenedione (N=4) and estradiol were assessed.

## Psychometric Tasks

These included the Wechsler Intelligence Scales for Children - Revised (WISC-R, Wechsler, 1974), or the Wechsler Adult Intelligence Scale (WAIS, Wechsler, 1967) when necessary; the Wide Range Achievement Test-Revised (WRAT-R, Jastak & Wilkenson, 1984) and the G.F.W. Auditory Memory Tests (Goldman, Fristoe & Woodcock, 1974).

## Laterality Tasks

Dichotic Listening. These consisted of three taped sets of synchronized stimulus pairs presented via a Sony TC-270 stereo tape recorder and Pioneer earphones. The syllables task consisted of 30 pairs of consonant-vowel combinations (pa, ga, ka, ba) presented at a rate of one per two seconds; the digits consisted of 12 sets of synchronized digit triad pairs presented at a rate of one digit per second with a 10 second intertriad interval; and the

melodies, which made use of commercial materials (Kimura, 1964), consisted of 12 trials involving the presentation of a pair of dichotically recorded melodies followed by four monophonically recorded melodies, two matching the dichotically presented melodies and two foils, randomly ordered. The subject was to report the syllables or digits heard or identify the two melodies that matched the ones presented dichotically. In order to control for any differences in loudness between the two channels, the syllables and digits tapes were administered twice, with the earphones reversed for the second set, and the earphones were reversed midway through the melodies tape. Each task was scored in terms of the number of items correctly reported for each ear.

Tachistoscopic Half-Field Tasks. Two tasks were presented via a Gerbands three-channel projection tachistoscope using two Kodak carousel projectors. Stimuli were projected randomly to the right or left visual fields, subtending an angle of 6 degrees of arc between the middle of the stimulus and a central fixation point. The subject sat in front of the equipment at a distance of 6 feet from the screen, with his or her head stabilized by a chin rest inserted into an opthalmic table. The dots task consisted of arrays presenting a random arrangement of three to eight dots shown on 35 mm slides; the letters task consisted of letter triads (none constituting a meaningful English word) arrayed vertically or horizontally on slides. Each task consisted of four practice trials and 20 test trials, 10 to the left visual field (LVF) and 10 to the right visual field (RVF) in random sequence. Slides were visible for 50 msec followed by a five second interstimulus interval. Performance was scored by tabulating the number of stimuli correctly reported for each visual field.

Dichhaptic Discrimation. This is a replication of Flanery and Balling's (1979) shape-discrimination task. It involved the simultaneous palpation by each hand of two abstract stimulus shapes followed by the presentation of a target shape by one hand only. The subject was to determine whether the target matched one of the two stimuli presented dichhaptically; stimuli were never visible.

The stimuli were generated randomly by Atteneave and Arnoult's Method I (1956); non-matching targets involved slight shape modifications. They were approximately 3.8 x 3.8 cm in size, and were cut from plywood 5 mm thick. Standard pairs were mounted on cardboard measuring 22.8 x 30.5 cm, 15 cm apart; target stimuli were centred on cardboard 15 x 22.8 cm. Stimuli were inserted into a plywood box, 50.5 cm x 39 cm x 30 cm, which was completely open on the experimenter's side. There were two holes 7 cm x 8 cm at the bottom of the side facing the subject through which she/he put her/his hands. A wooden partition between the two holes prevented cross-over.

The task consisted of four practice and 20 test trials representing all possible combinations of six unique stimulus pairs and four target conditions (matching, non-matching, right-hand, left-hand). Stimulus order was varied so that each hand felt all 12 stimulus shapes. For each trial, ten seconds were allowed for initial palpation while a maximum of five seconds was allowed for discriminating targets. Performance was scored by tabulating the number of correct responses for each hand.

Experimental Cognitive Tasks

(a) Visuospatial

Mental Rotation Tasks. Two tasks were given, one with two dimensional stimulus figures (arrows) and one with three-dimensional (blocks), shown paired in different spatial orientations. The object of the task was to determine whether the figures would have the same shape if they were in the same orientation.

The two-dimensional stimuli were arrow-like figures having an extra line that protruded from the end of one of the lines forming the arrow's point (Figure 1). Angular separations between the stimulus pairs varied from 0 to 180 degrees in increments of 15 degrees in the picture plane, thereby providing 13 unique rotation conditions. Half the items had matching figures while the remainder were non-matching with the extra line on the opposite side of the arrow

The three-dimensional stimuli were block-like shapes redrawn from the original Shepard and Metzler (1971) series to have one less arm. Angular separations between stimulus pairs varied from 0 to 180 degrees in increments of 20 degrees in the picture or depth planes, thereby providing 10 unique rotation sizes. Half of the items presented matching pairs while the remainder presented non-matching in the sense that the external arm of one figure was pointing in the opposite direction (Figure 1).

The 60 trials of both tasks represented three randomized blocks containing all possible combinations of the 10 or 15 rotation sizes and the two ("same" or "different") responses. Although two practice trials were usually provided with feedback, more trials were given if necessary. Both tasks were presented

via a Kodak 35 mm ektographic slide projector, connected to and controlled by an Apple II microcomputer. Subjects were instructed to respond "same" or "different" by pressing a response key on a button box connected to the microcomputer. All responses and reaction times were stored in the computer which was programmed to convert RTs to a linear model reflecting angular distances (Shepard and Metzler, 1971), the slope and intercept components of this model were used as indices of information processing.

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Insert Figure 1 about here

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Face Decoding. This was adapted from a facial expression discrimination paradigm of Walden and Field (1982) to serve as a visual counterpart of the letter decoding task (see below). It consisted of 96 pairs of cartoon-like drawings of faces shown via slides (see Figure 2). For one set of 48 slides, the face identity condition (FI), the task was to determine whether the stimuli represented the same face (i.e. that of the same person), regardless of expression; for the second set, expression identify (EI), the task was to determine whether the faces had the same expression, regardless of the identify of the face.

There were four distinct faces (two girls and two boys) and four different expressions (anger, happiness, sadness, and surprise). Each set had an equal number of same and different judgements. Half the subjects received the FI condition first, while the other half received the EI condition first. The task was presented via a Kodak 35 mm ektographic slide projector, connected to a microcomputer. Responses were made by pressing keys on a button box

attached to the microcomputer. Errors and RTs were recorded for same and different faces and for FI and EI conditions. The EI-FI difference was used as an estimate of facial decoding ability.

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Insert Figure 2 about here

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Figure Matching. This modification (Rovet, 1980) of the Matching Familiar Figures Test (Kagan, 1965) was used presently as a measure of visual discrimination, not impulsivity. It required a subject to select from an array of highly similar line drawings of familiar objects, one that exactly matched a given standard. Administration was via a test booklet containing 24 items showing a standard and set of variants on adjacent pages. Items were presented in four randomized blocks of six containing two, three, four, five, six, or eight variants. Latencies determined via stopwatch and errors were both recorded.

(b) Verbal

Letter Decoding. This was an adaptation of a task by Hunt, Lunneborg & Lewis (1975) based on the Posner, Boies, Eichelmon & Taylor (1969) "Name vs Physical Identity Paradigm". It involved the presentation via microcomputer of two sets of 60 letter pairs. For one set, the subject was instructed to label the two letters in a pair as "same", only if they were physically identical to one another (eg. "AA" or "bb"), while for the other, the letters were labelled "same" if they had the same name (eg. "Aa", "AA", "Bb", etc). The letters used in the task were A, B, G, H, a, b, g, and h.

The order of the two conditions was counter-balanced so that half the subjects received the Physical Identity (PI) condition first, while the other half received the Name Identity (NI) condition first. Each set contained an equal number of "identical" and "non-identical" pairs. The first 20 letter pairs of each set were practice trials. The subject responded by presenting one of two keys connected to the microcomputer, which stored responses and reaction times for NI and PI conditions and computed the NI-PI difference score. This score measured their verbal decoding rate.

Memory Scanning. This was a replication of Sternberg (1966, 1970) item recognition task, requiring a subject to determine whether a target stimulus was contained in a set of stimuli that varied in number of stimuli per set. Each trial involved the presentation via microcomputer of a series of one, three or five digits for a four second period. These were then followed by a two second interval, a warning beep, and a single-target digit that was or was not included in the original digit series. The target was enclosed in quotation marks to prevent confusion with the one-digit stimulus set. Subjects responded by pressing a response key connected to the microcomuter.

The task consisted of 60 trials representing 5 randomized blocks of two of each possible combinations of three set sizes and two response types. A minimum of two practice trials were given. All responses and reaction times were showed by the microcomputer, which also converted RT scores to a linear model reflecting set size.

Sentence-Picture Verification Task. This task was derived from studies by Carpenter and Just (1975) and MacLeod, Hunt, and Mathews (1978). It involved the presentation via microcomputer of successive sentence-picture pairs.

Sentences were either affirmative (eg. "Plus is above star") or negative ("Star is not above plus") and could be true or false about the picture which followed on the next slide. There were 48 trials representing six randomized blocks, each containing two of four sentence conditions: affirmative-true (AT), affirmative-false (AF), negative-true (NT), and negative-false (NF). The subject was required to read the sentence, press a key connected to the microcomputer to signify comprehension, after which a picture representing the sentence was shown. The subject was to indicate whether the picture was 'true' or 'false' of the sentence by pressing a designated key. A minimum of four practice trials were given until full comprehension of the task requirements was indicated. The computer stored responses and the two (comprehension and verification) reaction times for each trial. In addition all RT scores were submitted to a linear equation fitting the constituent comparison model of Carpenter and Just (1975), from which slope and intercept scores were derived.

Naming Speed. This task, which was based on a task by Spring and Capps (1974) requiring subjects to name stimuli as rapidly as possible, is thought to measure encoding speed. Three types of stimuli were provided - digits, colours, and pictures. The digits were presented in single rows of 50 randomly sequenced digits (excluding 0 and 7) printed on two 8 x 10 inch cards. The colours task consisted of 30 3/4" square colour patches arrayed on an 8 x 10" card in five rows and six columns and sequenced randomly, with no two adjacent patches being the same colour. Pictures consisted of 25 two inch square line-drawings of familiar objects arrayed on a 12 x 12 inch plate in rows and columns of five. Naming was from left to right and top to bottom (colours and pictures only).

Probed Serial Recall. This task, derived from Cohen and Sandberg (1977), assessed serial order recall of auditory information. It consisted of 12 tape-recorded lists of nine digits, each of which was followed by the letter A, B, or C. Subjects were instructed to repeat the first three digits in the list if "A" was said, the middle three if "B", and the last three if "C". The test was scored in terms of the number of digits correctly recalled for each of the three serial probes. According to Cohen and Sandberg (1977) recall of different list components reflect different cognitive mechanisms: primacy or beginning list items reflect rehearsal abilities, while recency or end-list recall reflect immediate recall from a passive "echoic" or acoustic store (Baddeley, 1976).

## Design and Analyses

Univariate and multivariate analyses of variance and covariance were used to compare the three groups; chronological age was the covariate in all of the analyses, except those involving tests where scores were already standardized by age. Factor analysis allowed for a reduction in the number of scores to provide generalized estimates of specific abilities. The contributions of biomaturational variables to outcome were studied using all possible subsets regression analyses; simple correlations were used to assess the relationships between hormonal and pubertal indices and outcome.

## RESULTS

### Physical Growth and Pubertal Development

Table 1 provides each group's mean values on the biomaturational indices. PPG subjects are clearly significantly advanced in their development while SSB are clearly retarded in both growth and pubertal development and DPG are delayed in sexual maturation. Two of the girls with PPG were menarcheal at the time of testing but, as yet, none of the girls with DPG. Although the three groups did not differ in pubic hair development (despite a four to five year age difference between PPG and the others), PPG were significantly more advanced in their breast development than DPG, $t(25) = 2.49$, $p < .02$.

There were no significant differences between PPG and SSB subjects in their hormone levels. According to the Hospital for Sick Children reference guide ("Reference Values", 1985) FSH, LH, and androstenedione (partial sample only) were in the prepubertal range, while testosterone was in early pubertal for both groups. Estradiol values of PPG, however, were clearly pubertal.

The lower TFRC values of girls than boys are consistent with those reported by others (Penrose, 1967); female subjects with advanced and delayed maturation rates did not differ from each other on this index.

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Insert Table 1 about here

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## Psychometric Findings

Table 2 presents the mean test scores for the WISC-R, WRAT, and GFW tests. Although a MANOVA indicated that the omnibus group difference for intelligence test results was not significant, $F(28,74) = 1.40$, univariate tests revealed the groups did differ in VIQ and FSIQ ($p < .01$). This was due primarily to the lower scores of girls with delayed puberty. For the individual subtests however, PPG scored significantly higher than growth-delayed children of both sex on the Similarities, Vocabulary and Comprehension; SSB scored higher than girls with both growth conditions on Object Assembly. Growth delayed children had higher PIQ than VIQ values (mean difference = -3.85 and -1.38), whereas growth-advanced had higher VIQ than PIQ scores (mean difference = 2.80), in keeping with Waber's hypothesis. This difference was not significant, however, $F(2,51) = 1.02$.

For the WRAT, a significant omnibus group difference was found, $F(12,90) = 3.08$, $p < .001$, which reflected the higher Spelling and Arithmetic scores of girls with precocious puberty. Although the groups did not differ in their performance on the GFW, precocious developers scored higher than delayed on all three subtests.

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Insert Table 2 about here

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## Specific Abilities

A principal components factor analysis was carried out on the verbal and spatial test scores for variable reduction. The verbal measures included the WISC-R Vocabulary, Similiarities, and Information subtest scores and the accuracy scores for the Sentence Verification, Letter Decoding and Memory Span tasks; the visuo-spatial measures were the WISC-R Picture Completion, Picture Arrangement, Object Assembly, Block Design subtest scores and the accuracy scores for the blocks and arrow rotation tasks. The results yielded four factors, two verbal and two spatial, comprised of either psychometrically- or experimentally-defined measures. The two verbal factors were labelled "Verbal Processing" and "Language Abilities" because of high loadings by the verbal experimental and WISC-R subtests while the two spatial factors were labelled "Spatial Rotations" and "Visuospatial Abilities" because mental rotation task indices and WISC-R spatial subtests loaded highly on each of these. In addition to the four factor scores, two composite scores, VERB and SPAT, were determined for each subject by averaging across the two verbal and two spatial factors and an ability difference score, VS, was determining by subtracting SPAT from VERB.

Table 3 presents the factor analysis and mean factor score results for the three groups. SSB scored significantly higher than PPG on the Spatial Rotation factor, $\underline{F}(2,44) = 4.34$, $\underline{p} < .01$ and PPG scored higher than delayed developers on the Language Abilities factor, $\underline{F}(2,44) = 4.68$, $\underline{p} < .01$, with similar trends for the other two factors. A MANCOVA revealed that the omnibus group difference was significant, $\underline{F}(8,82) = 3.00$, $\underline{p} < .01$.

Insert Table 3 about here

PPG had significantly larger VERB scores than SSB and DPG (.553 versus -.072, -.428), $F(2,44) = 6.26$, $p < .001$; SSB had significantly larger SPAT scores than the others (.275 versus -.325, -.379), $F(2,44) = 5.00$, $p < .01$. Figure 3 shows that PPG produced a large positive VS difference score, whereas SSB produced a large negative VS score, $F(2,44) = 6.59$, $p < .001$.

Insert Figure 3 about here

## Laterality

Dichotic syllables, digits and t-scope letters were designated as tasks of left hemisphere (LH) specialization because they dealt with verbal materials while dichotic melodies, t-scope dots and dichhaptic were assumed to reflect right hemisphere (RH) specialization because they dealt with nonverbal. The phi-coefficient (Kuhn, 1971) was selected for scoring these tasks because it measures degree of asymmetry independent of accuracy. This is determined by subtracting the results for the presumed non-dominant hemiphere from those for the presumed dominant according to formula.

A MANCOVA indicated the groups differed in their overall laterality, $F(12,04) = 2.04$, $p < .03$, with significant differences on two of the dichotic listening tasks. Neuman Keuls tests revealed that SSB had significantly

larger phi-scores than PPG on the syllables (.112 versus .082) and melodies tasks (.011 versus -.109), $F(2,44) = 3.36$, $p < .05$ and $F(2,44) = 2.84$, $p < .06$ respectively.

Mean LH and RH phi scores, determined by averaging across appropriate tasks, are shown in Figure 4. All three groups produced right-sided (or left hemisphere) advantages for the tasks involving verbal materials. Although the groups did not differ significantly on the LH tasks, SSB and DPG produced stronger lateral asymmetries than PPG, with SSB stronger than DPG. For the three tasks involving nonverbal stimulus information, only SSB demonstrated the appropriate left-sided or RH advantage. On these tasks, the difference between SSB and PPG was marginally significant ($p < .10$), in line with the Waber hypothesis.

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Insert Figure 4 about here

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In order to determine to what degree ability was affected by laterality, LH and RH scores were regressed on each of the major ability variables (i.e IQ and factor scores). The results revealed a significant positive association between LH and some of the spatial, but none of the verbal, ability scores. LH accounted for 6.5% of the variance in PIQ, $t(50) = 1.91$, $p < .06$; 8.4% of the variance on the Visual Processing factor, $t(50) = 2.05$, $p < .05$; 10.3% of the variance in SPAT $t(50) = 2.26$, $p < .03$; and 10.5% of the variance in VS, $t(50) = -2.27$, $p < .03$. Although RH did not significantly predict performance on any of the summary indicators, the relationships were consistently negative signifying that better verbal and spatial ability are associated with weaker RH lateralization.

## Cognitive Experimental Measures

### Visuospatial Tasks

Mental Rotation. A MANCOVA (age as covariate) was computed on the accuracy and RT scores of the two mental rotation tasks. The results indicated no omnibus group effect, $F(20,86) = 1.07$. Univariate tests revealed that the groups performed significantly differently on the Arrows task, $F(2,39) = 5.14$, $p < .01$; growth-delayed children outperformed girls with precocious puberty (7.3 and 14.6 versus 19.9 errors). A similar trend was also noted for blocks (9.7 and 12.5 versus 15.0 errors). The only reaction time index on which the groups differed significantly was the intercept score for the blocks task, $F(2,41) = 3.07$, $p < .05$. As shown in Figure 5, this reflects the smaller intercept scores of boys with short stature, which signifies that they required less time to encode visuospatial information. A similar, though not significant, difference was also observed for the Arrows task. The groups did not differ significantly in their slope components.

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Insert Figure 5 about here

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Face Decoding. The groups did not differ in accuracy or RT in matching faces or facial expressions, or in their EI-FI differences. The mean error scores for face matching were .45, .17, and 1.0 for SSB, DPG, and PPG and their mean latencies were 1.22, 1.38, and 1.84 seconds respectively. For expression matching, the mean error and latency scores were 3.32, 3.00, and 3.56 and 1.93, 2.30, and 2.91 seconds respectively.

Matching Figures. The groups did not differ in accuracy on this task. DPG responded marginally quicker than SSB and PPG (21.7 versus 26.8 and 25.4 seconds), $t(50) = 1.83$, $p < .06$.

Verbal Tasks

The results of a one-way MANCOVA indicated the groups did not differ in their processing of verbal information as measured by the letter decoding, memory scanning, and sentence verification tasks.

Letter Decoding. Univariate tests reveal that the groups did not differ significantly in their performance on this task. The NI-PI difference was slightly, though not significantly, larger for DPG and PPG than SSB (186.9 and 217.4 versus 101.3)

Memory Scanning. DPG had significantly faster RTs than the other groups, $F(2,49) = 3.11$, $p < .05$, (1.56 versus 1.81 for SSB and 2.03 for PPG). This was particularly evident for the five stimulus set items (1.64 versus 2.00), and 2.02, $F(2,49) = 7.66$, $p < .001$), and contributed to a difference of marginal significance in their slope values, $t(50) = 1.87$, $p < .09$.

Sentence-Picture Verification. Although the groups did not differ significantly on any of this task's parameters, SSB were affected to a greater degree by sentence complexity than DPG and PPG, as indicated by their steeper comprehension slopes (see Figure 6). This also raises the possibility that they may have been using different strategies than girls to comprehend complex verbal information (McLeod et al, 1978). This difference was not evident for verification rates (Figure 6).

Insert Figure 6 about here

Probed Serial Recall The data for this task were submitted to a 3 (group) x 3 (position) repeated measures ANCOVA. The results revealed a significant serial position effect, $F(2,74) = 35.25$, $p < .001$, reflecting generally better recall for final list or recency items across groups. Also significant was the interaction, $F(4,74) = 3.84$, $p < .01$, which when decomposed reflected group differences on mid and end-list items (Figure 7). SSB recalled significantly ($p < .02$) more mid-list items than PPG, while SSB and PPG both recalled significantly ($p < .01$) more final-list items than DPG.

Insert Figure 7 about here

Naming Speed. The results of a 3 (group) x 3 (task) ANCOVA (age as covariate) revealed a significant task effect, $F(2,44) = 189.2$, $p < .001$, and a group x sex interation, $F(4,44) = 3.61$, $p < .01$. As shown in Figure 8 encoding rates were slower for digits than colours or pictures (2.35 versus 1.40 and 1.30 seconds). Decomposition of this interaction effect revealed that PPG were faster than DPG and SSB, but only with the picture and colour stimuli.

Insert Figure 8 about here

## Biomaturational Effects

All possible subset regression analyses were used to determine the biomaturational factors that best predicted outcome. Seven predictors were entered into the equation -- TFRC, height (standard scores), bone age (BQ), pubertal developmental rate (PQ), age, sex, and pubertal state (prepubertal vs pubertal). The significant results of these analyses are listed in Tables 4, 5, and 6.

### General Abilities

Table 4 shows that for the IQ measures, only VIQ was affected by maturational factors. The regression analysis revealed that VIQ was best predicted by pubertal rate, which accounted for 11% of its variance. The relationship was such that children with more advanced pubertal rates obtained higher VIQ scores.

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Insert Table 4 about here

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Pubertal development was also a significant predictor of the Verbal Processing factor score (comprised of experimental task measures) and the VERB score, accounting for 12.7% and 24.2% of the variance respectively. These relationships reflected better verbal task performance by children with more advanced pubertal development. Chronological age was a significant predictor of the Language factor score (comprised of psychometric test measures), accounting for 19.3% of its variance.

A model involving both pubertal development and sex was selected for the Spatial Rotations factor score, accounting for 33% of its variance. Being

male and being developmentally delayed predicted better spatial performance. There were no significant predictors of the Visuospatial Ability factor. Sex significantly predicted SPAT, accounting for 20% of its variance. Pubertal developmental rate was the major predictor of the difference between Verbal and Spatial scores (VS), accounting for over 27% of its variance. This reflected the greater the spatial advantage over verbal in relation to delay in pubertal development.

These results therefore signify that rate of pubertal development does play a major role in determining specific cognitive abilities. Advanced pubertal development is associated with better verbal, but poorer spatial, skills, thereby supporting the Waber hypothesis.

Laterality

Pubertal development was a significant predictor of left hemisphere lateralization accounting for 11% of the variance, with greater developmental delays contributing to stronger lateral biases. A model involving both fetal and pubertal development indices significantly predicted right hemisphere lateralization, jointly contributing 20% to its variance (Table 5). For RH tasks, stronger lateral biases were associated with larger pubertal delays and with faster rates of uterine growth.

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Insert Table 5 about here

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Specific Cognitive Abilities

Table 6 presents the findings from the regression analyses involving the cognitive processing task results. Biomaturational variables were significant predictors of the majority of these task parameters.

Visuospatial. A number of components of spatial processing were predicted by biomaturational factors. Delayed (for age) pubertal development was associated with greater accuracy on both rotation tasks. A model involving stature and bone development significantly predicted intercept values on the blocks task: children with slower pubertal growth rates (particularly boys) performed better on the spatial processing tasks; children less advanced in physical growth (height, bone age) produced slower mental rotation task encoding rates. Age was a major predictor of visual discrimination ability (younger, better), while pubertal state was associated with rate of discriminating different faces (children in puberty took longer than children who were prepubertal).

Verbal. Pubertal development, sex, age, and skeletal maturation were all found to predict different aspects of cognitive functioning on verbal processing tasks. Faster rates of pubertal development were associated with higher accuracy, slower reaction times, and less steep slopes on the memory scanning task; steeper slopes in the verification component of the Sentence Verification task; and slower naming speeds. Older children, particularly boys, also responded more quickly on the memory scanning task. On letter decoding, children who were currently pubertal produced larger RT differences between name identify and physical identify matches, while children with higher TFRCs made fewer errors on this task.

Recall of different list items of the serial recall task appeared to be controlled by different biomaturational factors. Rate of pubertal development predicted recall of primacy or beginning-list information; chronological age predicted mid-list performance; and bone age and sex both predicted recall of recency or end-list information. Children who were more delayed in their

pubertal development did better with earlier items, while children with advanced bone ages and boys did better with recent information (see Figure 7).

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Insert Table 6 about here

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## Correlations with Pubertal Stages and Hormones

Correlations were obtained between hormone levels and Tanner stages with the major outcome variables - VIQ, PIQ, factor scores, VERB, SPAT, VS, and left and right hemisphere laterality scores. These were computed for each of the three groups separately. Table 7 presents the significant findings.

Although no clear pattern emerged, there are some consistencies in the data which suggest that levels of verbal and spatial ability appear to be controlled by hormonal levels and degree of sexual maturity. Moreover, laterality test results correlated only with pubertal stage data, not any of the hormonal measurements, with the two hemispheres being affected differently for SSB and PPG. This reflected the observation that among SSB, those with greatest pubertal delays (i.e. who were more atypical) produced stronger lateral asymmetries on the right hemisphere tasks, whereas among PPG, those with less advanced pubertal development (i.e. who were less atypical) produced stronger asymmetries, but on the left hemisphere tasks.

Hormonal measurements were available for a subsample of children in the SSB and DPG groups (see Subjects). With regard to gonadotropin levels, higher FSH values were associated with poorer verbal ability in SSB but better

spatial ability in PPG. Higher LH values were associated with lower verbal and spatial ability in SSB and with lower verbal in PPG. Since FSH and LH values are usually higher for individuals who are pubertal, these results suggest that within the SSB group, those who were less developed had better verbal and better spatial ability than those who were more developed. Within the group of growth advanced girls, those with more advanced puberty had better spatial but weaker verbal ability than those with less advanced. With regard to the sex steroid hormones, SSB with higher testosterone (i.e. more mature) levels had better verbal but poorer spatial ability, whereas PPG with higher estrogen levels had better spatial ability. There were two few children with androstenedione measurements to compute correlations (SSB, N=3; PPG, N=4).

Because pubic hair development was not associated with either verbal or spatial ability whereas the development of secondary sex characteristics was (at least for boys), it is possible that the pubertal events controlled by secretions from the adrenal glands (adrenarche) may make little if any effect on specific cognitive abilities.

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Insert Table 7 about here

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## DISCUSSION

Unlike our previous research, the present findings demonstrate that children with atypical pubertal development do perform in a manner consistent with Waber's hypothesis. Girls with precocious puberty outperformed children

with delayed development on tasks of verbal ability, whereas children with delayed development outperformed girls with advanced on tasks of spatial ability. These results also agree with Galatzer and Gordon (1982) who observed an advantage on verbal tasks by females with precocious puberty and an advantage on verbal by males and females with constitutionally delayed puberty and with Meyer-Bahlburg et al. (1985) who observed that adolescent females with precocious puberty scored lower than matched controls in spatial ability. Hence, better verbal ability is clearly associated with a faster rate of physical maturity whereas better spatial ability is clearly associated with a slower maturation rate. The regression analyses showed that of the seven biomaturational predictors considered, pubertal maturation rate was the most frequent predictor of the differences in levels of ability that were observed.

Maturation rate effects were also observed on tasks of hemispheric specialization. A slower developmental rate resulted in stronger cerebral lateralization as evidenced by (i) the larger lateral asymmetries on tasks of left hemisphere specilization by children with delayed development and (ii) the stronger right hemisphere biases by growth delayed children (boys only) for tasks involving nonverbal materials. (On the right hemisphere specialization tasks, girls with precocious puberty were more atypical than girls with delayed). Galatzer and Gordon (1982) report very similar performance by children with these conditions on tasks of right and left hemisphere cognitive function; Meyer-Bahlburg et al (1985) report a slight weakness in right hemisphere functioning but no effect for left.

Thus, fast and slow developers differ both in specific abilities and in patterns of hemispheric organization in the manner specified by Waber. It is

tempting to deduce from this that the relationship between patterns of abilities and developmental rate is in some manner mediated by the relationship of maturation rate on hemispheric organization. However, although laterality and abilities were each significantly correlated with pubertal rate, they were not strongly correlated with each other. The only significant relationship was found between spatial ability and degree of left hemisphere bias for tasks involving verbal materials; neither verbal nor spatial ability were correlated with performance on tasks assessing right hemisphere specialization. These results therefore signify that the relationship appears to be more complex than originally conceived (Waber, 1977) and in fact maturation rate effects may be influencing laterality and ability independently of each other. This finding also gains support from studies by Hines and Shipley (1984) with females who were exposed prenatally to diethylstilbestrol (DES), a synthetic hormone which is recognized to masculinize the neural structure and function of affected individuals (Hines and Gorski, 1985). They found that DES-exposed women were strongly lateralized, but did not have better spatial ability.

As also observed by Waber al (1985), the experimental task data provided clues as to the components of verbal and spatial processing that were most affected by maturation rate phenomena. On spatial tasks, boys with delayed development (who demonstrated better pschometrically-defined spatial ability) had significantly shorter intercept values for a task involving complex visuospatial information and showed a similar trend for tasks involving simple and familiar stimulus information; they did not differ in their slope values. This suggests that they are probably more efficient at encoding visuospatial

stimulus information (Cooper, 1976), while still using the same transformational strategies to solve these problems. The regression analyses showed that the differences in intercept values were primarily due to variations in general physical maturation (stature, bone age), not pubertal maturation or sex.

Similarly, the three groups of children also differed on selective components of verbal processing tasks in a manner consistent with the psychometric test results. Examining these data according to the order in which verbal information is processed, we found that DPG (who had the lowest VIQs) demonstrated less attentional capacity for incoming verbally-presented material, as evidenced by their poorer recency scores on the Probed Serial Recall task (see Hunt 1978). Both DPG and SSB were slower than PPG in naming nonverbal stimuli (pictures, colours), but they did not differ in rate of naming verbal stimuli (digits), decoding verbal information (letter decoding) or memory capacity (digit span). On the other hand, DPG showed a recall advantage for visually presented information as indicated by their RT slopes on the memory scan task. Together these findings suggest that the verbal advantage of girls with precocious puberty may be related to either how they process ongoing acoustically-presented information or to greater verbal fluency or both.

The results of sentence-picture verification task, designed to tap competence in processing linguistic information (Carpenter & Just, 1975), showed that growth-delayed boys produced marginally steeper slopes for comprehending verbal information. This can be interpreted as they were either having greater difficulty in processing grammatical information (Hunt, 1978) or were using a different cognitive strategy (MacLeod et al, 1978). However,

because the constituent comparison model of Carpenter and Just (1975) significantly fit their comprehension and verification scores ($r = .383$, $p < .05$ and $\underline{r} = .630$, $\underline{p} < .01$), it seems likely that SSB were using a verbal, not a spatial, strategy (MacLeod et al 1978) to solve these problems. The regression analyses revealed that a number of selective components of verbal processing were controlled by rate of pubertal maturation. These included VIQ; Memory Scanning accuracy, slope and intercept values; Sentence Verification slopes and reaction times; and Naming Speed. The nature of the relationship was such that faster pubertal development rates were associated with better performance on these tasks.

It is also interesting to note that one of the two indices of cognitive processing significantly predicted by pubertal state was speed in matching faces. The fact that children in puberty took longer to discriminate faces than children who were prepubertal, provides some support for the assertion by Carey and Diamond (1980) that disruptions in the performance of this skill may occur during puberty, but there is no evidence that this occurs for other right hemisphere tasks or for degree of right hemisphere specialization.

Hormone levels correlated with ability measures, but not laterality. For SSB higher levels (signifying greater maturity) were associated with poorer spatial ability, and either poorer or better verbal ability, depending on the hormone (FSH and LH were associated with lower verbal ability while testosterone was associated with better). For PPG, however, higher hormonal concentrations were associated with better spatial, but poorer verbal ability, contrary to prediction. These results signify, therefore, that the relationships we observed between groups or when the entire sample was examined do not necessarily hold when children are compared within their

respective groups. Since the girls with precocious puberty who were more mature at the time of testing (i.e. more atypical) had better spatial but poorer verbal ability than those who were less mature, whereas the boys with delayed development who were more mature (i.e. less atypical) had better verbal but poorer spatial ability, this suggests that relative maturation (i.e. whether the child is advanced for age or delayed for age) as well as maturation rate itself (i.e. how fast or how slow) both affect cognitive function. It is unfortunate that comparable data were not available for growth-advanced boys or growth-delayed girls in order to assess the role of sex in these relationships. Our current findngs, which indicate that a slower rate of pubertal maturation enhances both the typical male (high spatial-low verbal) and female (high verbal-low spatial) cognitive profiles (Maccoby and Jacklin, 1974), also point to the possibility of an interaction of sex with rate of maturation. These results, which differ from those reported by Gordon and Lee (1986) must be interpreted with caution, however, because they are not based on our total sample nor have the hormonal measurements been controlled for monthly phase or daily cycle. Furthermore, some of the children were also receiving treatment at the time of assessment.

Regarding pubertal stage data, our results indicated that more advanced pubic hair development was associated with weaker RH lateralization in SSB and weaker LH lateralization in PPG. More advanced testicular development was associated with poorer spatial but generally weaker verbal ability in SSB while breast development was associated with poorer verbal skills in DPG. These results, like the hormonal data, show that maturation produces the predicted set of relationships in boys but not girls.

In summary, the results of this study have provided positive support for Waber's hypothesis that differences in ability and laterality both appear to reflect rate of pubertal maturation. A slower maturation rate was associated with better spatial but poorer verbal ability and stronger right and left hemisphere specialization. The fact that maturation affected laterality and abilities independently of each other suggests that the effects of maturation in laterality is not the mechansim contributing to the ability differences. Rather, our findings with the cognitive processing tasks suggest that the maturation-related ability differences may be occurring at the level of microcomponents of specific abilities, which are not necessarily dependent on a single hemisphere (Gevins et al, 1982; Tucker, Dawson, Roth and Penland, 1985).

Although the results of the regression analyses have identified rate of pubertal maturation as the major factor contributing to these differences - beyond that of general somatic development - we are still left with determining what that factor might be. Some have argued that hormonal concentrations are the mechanisms contributing to such differences (Gorden and Lee, 1986; Hines and Shiply, 1985). Our results indicate that while this might indeed by the case, the results appear to differ depending on sex and/or maturational problem (i.e. advanced or delayed for age). Because our findings are based on small sample sizes and may be biased by using referral populations, further investigations of this problem are undoubtedly necessary before the 'cause' of the Waber effect can be adequately isolated.

It is also important to note that degree of hemispheric specialization was found to depend on developmental factors preceding birth in addition to factors related to the timing of puberty. This suggests that while the stage

may indeed be set early in life, including before birth, ultimate hemispheric specialization may depend on processes associated with the advent of puberty. Our hormonal data, however, indicate that hormones do not appear to be the cause.

Finally, we are left in closing with answering the question why the children in this study performed as Waber would predict, whereas those in our previous study did not, despite the fact that both involved children with the same atypical growth conditions. Our best guess is that the differences in the two studies reflected sampling differences, which include the smaller age difference between groups presently (thereby allowing us to compare groups directly rather than by matching with normal controls), the smaller age ranges within the groups, and the use of age as a covariate in the present study. The results of the regression analyses, the majority of which showed pubertal maturation to significantly predict outcome, provide independent confirmation for the present investigation.

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Table 1

Mean (SD) Biomaturational Measure Scores

| | Short Stature Boys (N = 27) | Delayed Puberty Girls (N = 15) | Precocious Puberty Girls (N = 13) |
|---|---|---|---|
| Age at Testing | 13.9 (1.1) | 12.6 (2.2) | 8.5 (1.5) |
| Age at Diagnosis | 12.1 (2.1) | 11.5 (1.8) | 6.3 (2.2) |
| Pubertal Age | 11.8 (1.8) | 10.8 (1.6) | 11.3 (1.5) |
| Bone Age | 11.1 (1.8) | 10.4 (2.0) | 9.1 (2.1) |
| Weight (kg) | 35.1 (9.1) | 32.2 (5.9) | 38.2 (10.4) |
| Height (cm) | 139.2 (10.5) | 121.8 (37.8) | 139.9 (9.4) |
| Height %ile | 1.5 (2.9) | 78.2 (30.8) | 99.3 (2.2) |
| Breast Stage | | 1.57 (.62) | 2.46 (1.29) |
| Pubic Hair Stage | 2.02 (.87) | 1.82 (.93) | 1.92 (.73) |
| Testicular Vol (cc) | 5.71 (3.26) | | |
| Penile length (cm) | 6.70 (1.87) | | |
| FSH (U/liter) | 5.00 (1.41) | | 5.10 (1.36) |
| LH (U/liter) | 3.33 (1.37) | | 3.80 (1.49) |
| Estradiol (pmol/L) | | | 172.10 (74.1) |
| Testosterone (nmol/L) | 2.07 (2.20) | | 0.52 (.13) |
| Androstenedione (nmol/L) | 1.50 (0.87) | | 0.60 (.25) |
| TFRC | 147.8 (43.6) | 126.6 (52.0) | 122.5 (58.2) |

Table 2

Mean Psychometric Test Scores

| | Short Stature Boys (N = 25) | Delayed Puberty Girls (N = 15) | Prec Puberty Girls (N = 13) | F-value |
|---|---|---|---|---|
| VIQ | 97.8 | 94.6 | 105.1 | 5.22** |
| PIQ | 101.9 | 95.9 | 102.3 | 2.5 |
| FSIQ | 101.2 | 95.0 | 99.4 | 4.51** |
| Information | 9.4 | 9.1 | 10.0 | 2.61 |
| Similarities | 9.7 | 9.3 | 11.0 | 4.74** |
| Arithmetic | 10.1 | 8.8 | 9.4 | 2.25 |
| Vocabulary | 9.8 | 9.3 | 12.3 | 4.81** |
| Comprehension | 9.5 | 9.4 | 11.9 | 5.08** |
| Digit Span | 8.4 | 9.5 | 10.7 | 2.24 |
| Picture Comprehension | 10.3 | 9.9 | 10.5 | 0.34 |
| Picture Arrangement | 10.3 | 10.4 | 10.9 | 0.75 |
| Block Design | 10.9 | 9.4 | 10.3 | 2.37 |
| Object Assembly | 10.8 | 8.3 | 9.5 | 4.62** |
| Coding | 9.0 | 9.2 | 10.7 | 2.24 |
| WRAT (%ile) | | | | |
| Reading | 52.2 | 59.5 | 65.2 | 2.80 |
| Spelling | 43.5 | 50.4 | 57.3 | 3.15* |
| Arithmetic | 22.5 | 21.2 | 49.8 | 18.49*** |
| GFW (%ile) | | | | |
| Recognition | 49.3 | 46.3 | 52.5 | |
| Content | 50.6 | 51.2 | 53.6 | |
| Sequencing | 36.3 | 37.5 | 45.0 | |

*p < .05; **p < .01; ***p < .001

Table 3

Mean Factor Score Results

| | Eigenvalue | SSB | DPG | PPG | p-level |
|---|---|---|---|---|---|
| Verbal Processing | 2.4 | .001 | -.379 | .438 | |
| Language Abilities | 2.39 | -.145 | -.478 | .668 | .01 |
| Spatial Rotations | 3.78 | .311 | -.281 | -.701 | .01 |
| Visuospatial Abilities | 2.18 | .238 | -.370 | -.050 | |

Table 4

Significant Predictors of Ability Measures

| | Predictor | t-value | p-level |
|---|---|---|---|
| VIQ | Pubertal Development | 2.11 | .05 |
| Verbal Processing | Pubertal Development | 2.42 | .02 |
| Language | Age | -3.13 | .003 |
| Spatial Rotations | 1. Pubertal Development | -2.88 | .006 |
| | 2. Sex | -2.01 | .05 |
| VERB | Pubertal Development | 3.63 | .001 |
| SPAT | Sex | -3.20 | .003 |
| VS | Pubertal Development | 3.93 | .000 |

Table 5

Significant Predictors of Laterality Task Asymmetries

| | Factor | t-value | p-level |
|---|---|---|---|
| Left Hemisphere | Pubertal Development | -2.44 | .031 |
| Right Hemisphere | 1. TFRC | 2.58 | .014 |
| | 2. Pubertal Develop | -2.07 | .045 |

Table 6

Significant Predictors of Experimental Cognitive Measures

| | Predictors | t-value | p-level |
|---|---|---|---|
| I. VISUOSPATIAL | | | |
| Arrows - Accuracy | 1. Sex | -2.55 | .015 |
| | 2. Pubertal Development | -2.54 | .015 |
| Blocks - Intercept | 1. Stature | 2.97 | .005 |
| | 2. Bone Age | -2.02 | .050 |
| - Accuracy | Pubertal Development | -3.93 | .000 |
| Matching Figures | | | |
| Accuracy | Age | -3.94 | .000 |
| Matching Faces | | | |
| Faces - RT Same | Age | -2.47 | .019 |
| - RT Diff | Pubertal State | 2.17 | .038 |
| Faces - Expressions | Age | 2.11 | .043 |
| II. VERBAL | | | |
| Memory Scanning | | | |
| RT | 1. Sex | -2.46 | .018 |
| | 2. Age | -3.14 | .003 |
| RT (5 set size) | 1. Age | -4.22 | .000 |
| | 2. Sex | -3.96 | .000 |
| Intercept | 1. Pubertal Development | -2.40 | .021 |
| Slope | 1. Age | -4.02 | .000 |
| | 2. Pubertal Development | -2.96 | .006 |
| | 3. Bone Age | -2.71 | .011 |
| | 4. Sex | -2.46 | .019 |
| Accuracy | Pubertal Development | 2.97 | .005 |
| Sentence Verification | | | |
| Verification Slope | Pubertal Development | 2.40 | .005 |
| Verification RT | Pubertal Development | 2.22 | .032 |
| Letter Decoding | | | |
| Errors | TFRC | -2.12 | .040 |
| NI-PI | Pubertal State | 1.99 | .053 |
| Naming Speed | Pubertal Development | -4.05 | .000 |
| Probed Serial Recall | | | |
| A items | Pubertal Development | -2.19 | .036 |
| B items | Age | 2.24 | .032 |
| C items | 1. Bone Age | 3.16 | .004 |
| | 2. Sex | -2.14 | .040 |

Table 7

Significant Simple Correlations of Hormone Levels and Pubertal Stages with Outcome Measures

| Group | Hormone/Stage | Significant Correlations | |
|---|---|---|---|
| | | Ability Measures | Laterality Measures |
| SSB | FSH | VIQ (-) | - |
| | LH | VIQ (-), PIQ (-), SPAT (-) | - |
| | Testosterone | PIQ (-), VERB, SPAT (-) | - |
| | Pubic Hair | - | RH (-) |
| | Testes | VIQ (-), PIQ (-), Verbal Processing | RH (-) |
| DPG | Pubic Hair | - | - |
| | Breast | VERB (-) | - |
| PPG | FSH | SPAT | - |
| | LH | Verbal Processing (-) | - |
| | Estrogen | Visuospatial | - |
| | Pubic Hair | - | LH (-) |
| | Breast | - | LH (-) |

## Figure Captions

Figure 1 Sample items from the rotation tasks. a. Arrows Task, "same" judgement item; b. Blocks Task, "different" judgement item.

Figure 2 Sample items from the Face Decoding Task. a. Same faces, different expressions; b. Different faces, same expression.

Figure 3. Mean verbal-spatial difference scores of delayed and advanced growth subjects. Scores above axis signify better verbal than spatial ability; scores below axis signify better spatial than verbal ability. Differences significant between SSB and PPG, $\underline{t}(39) = 3.62$, $\underline{p} < .001$, and between DPG and PPG, $\underline{t}(26) = 2.55$, $\underline{p} < .01$.

Figure 4. Mean phi-scores on laterality tasks. Scores above axis signify a left hemisphere response bias; score below axis signify a right hemisphere response bias.

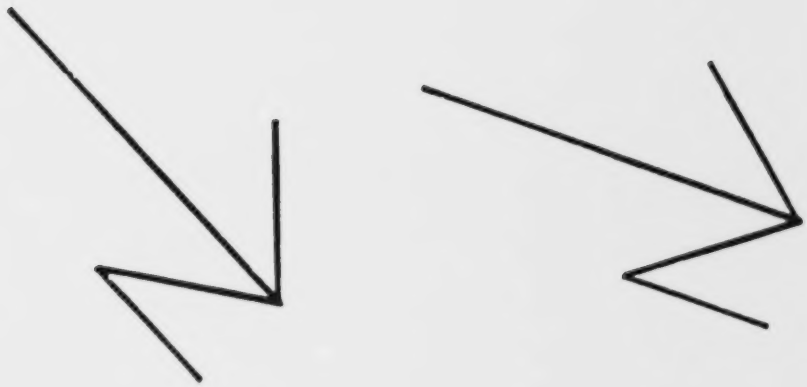
Figure 5. Linear regression of reaction time on angular distance for 2-dimensional (arrows) and 3-dimensional (blocks) tasks (Note: SSB is represented by filled circles, DPG by open circles and PPG by filled squares).

Figure 6. Linear regressions of reaction time on sentence complexity for comprehension and verification components of Sentence Verification task (note: SSB is represented by filled circles, DPG by open circles and PPG by filled squares).

Figure 7. Mean number of items recalled on the Probed Serial Recall task. Filled circles = SSB, open circles = DPG, and filled squares = PPG.

Figure 8. Mean encoding rates on Naming Speed task. Filled circles = SSB, open circles = DPG, and filled squares = PPG.

(a)



(b)

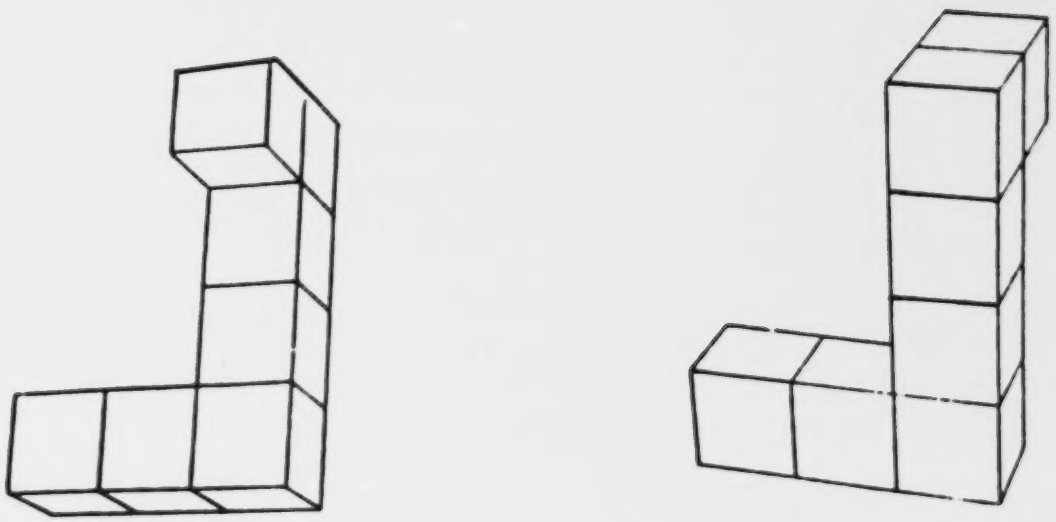


figure 2

(a)

)

Figure 3

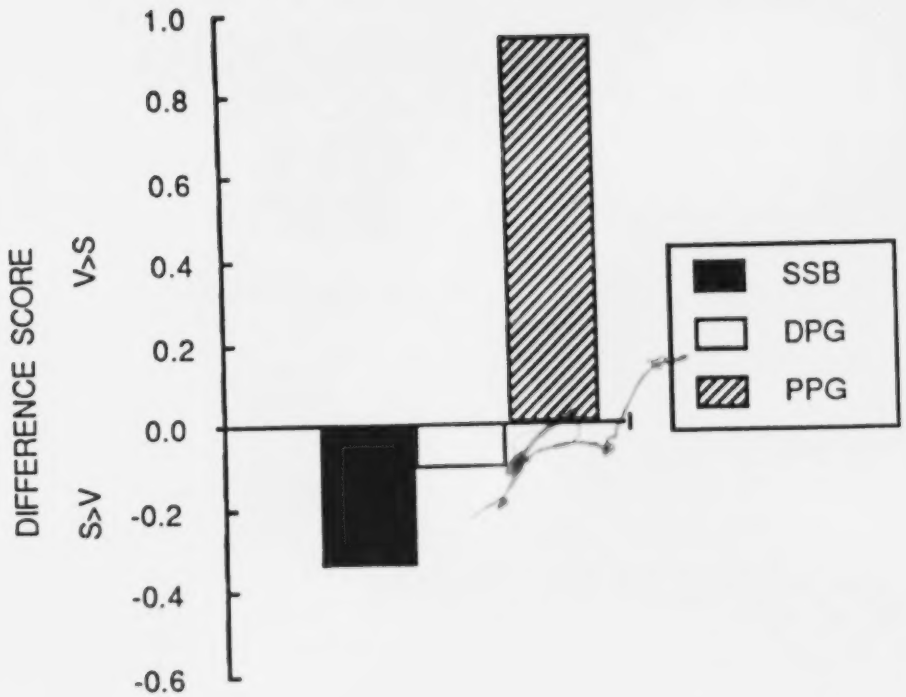
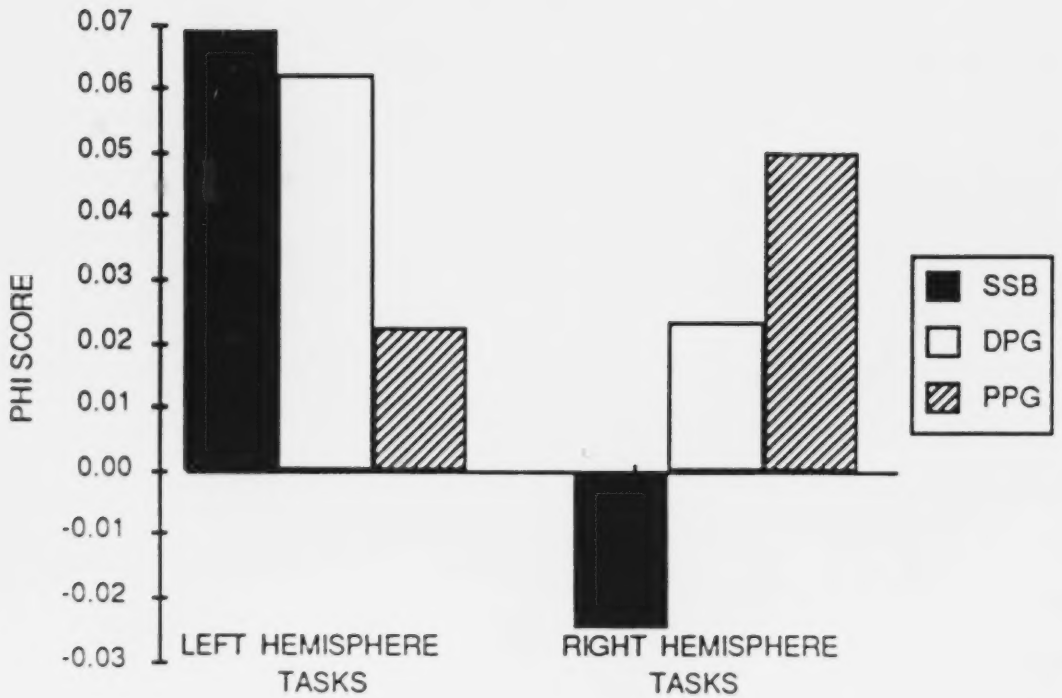


Figure 4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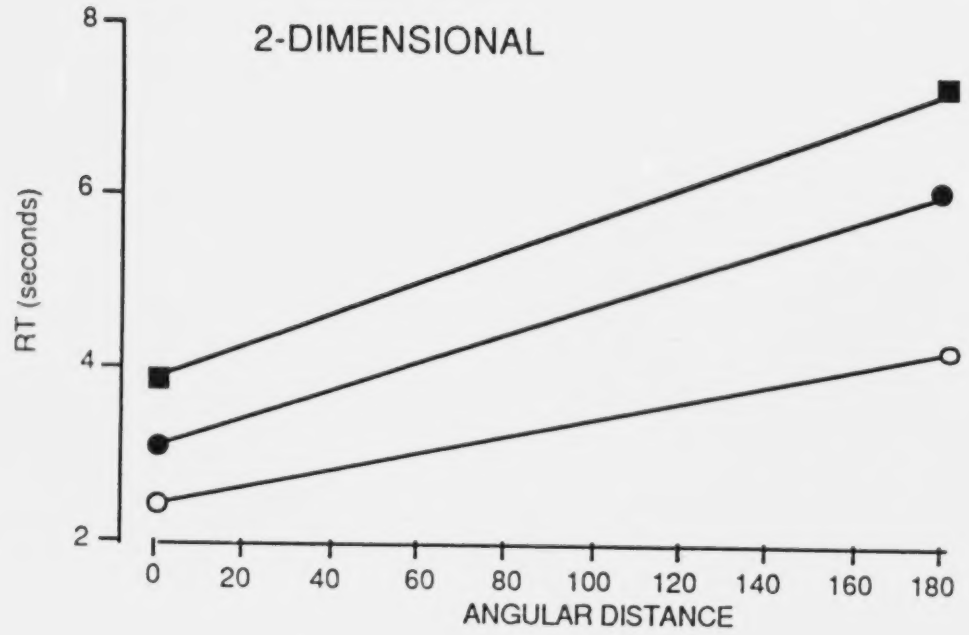
0.05
0.04
0.03
0.02
0.01
0.00
-0.01
-0.02
-0.03
PHI SCORE
LEFT HEMISPHERE TASKS
RIGHT HEMISPHERE TASKS
SSB
DPG
PPG

Figure 5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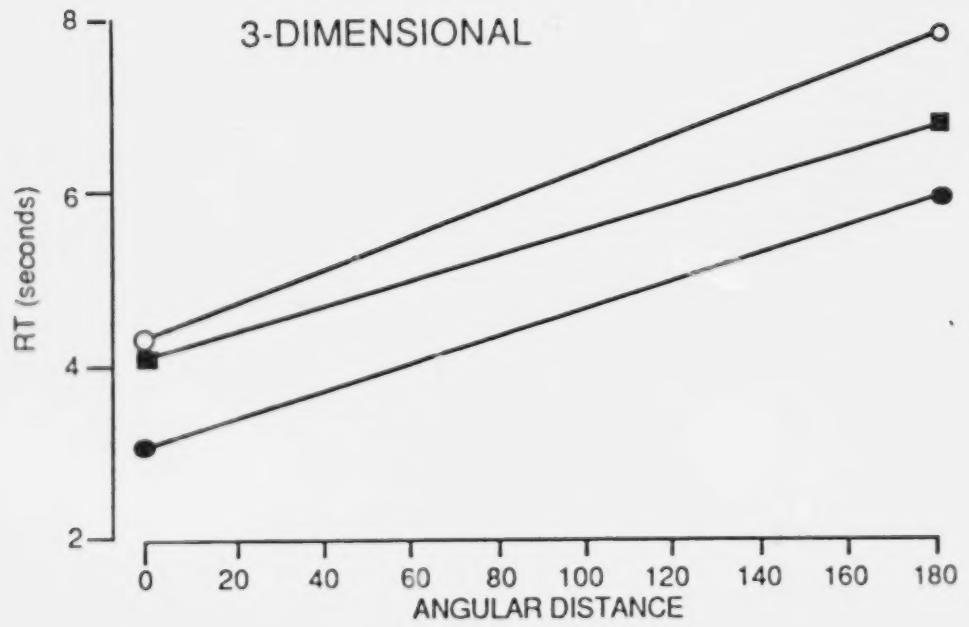
6
4
2
0
20
40
60
80
100
120
140
160
180
ANGULAR DISTANCE


3-DIMENSIONAL
RT (seconds)
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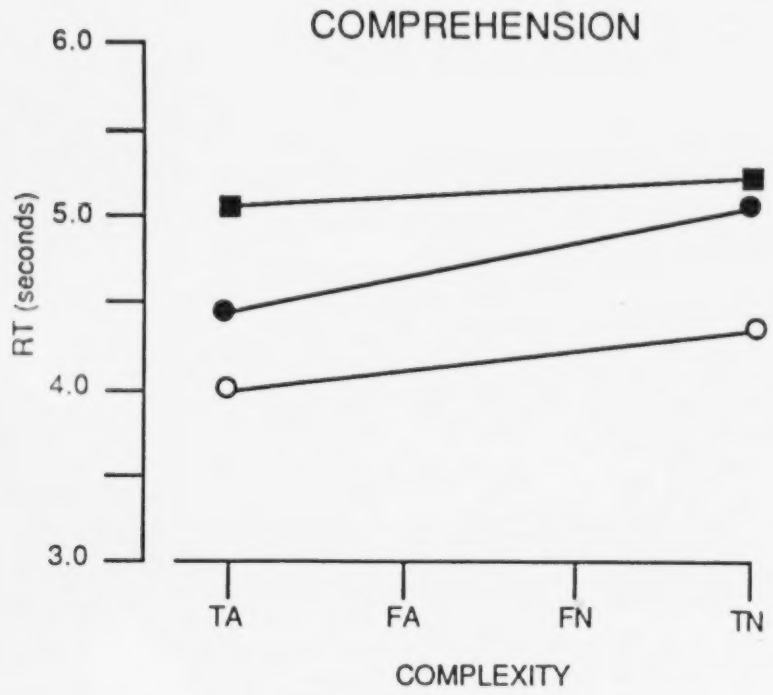
6
4
2
0
20
40
60
80
100
120
140
160
180
ANGULAR DISTANCE

Figure 6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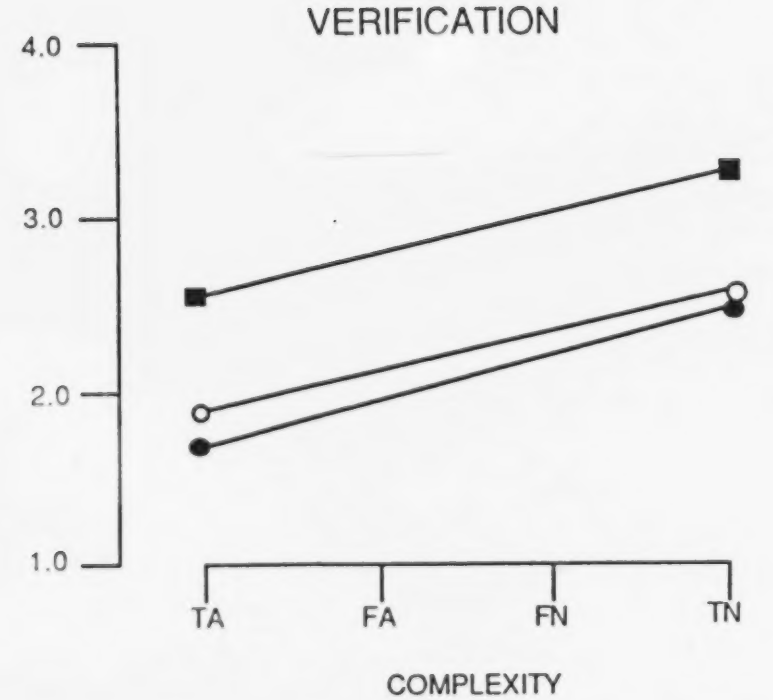
5.0
4.0
3.0
RT (seconds)
TA
FA
FN
TN
COMPLEXITY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3.0
2.0
1.0
TA
FA
FN
TN
COMPLEXITY

Figure 7

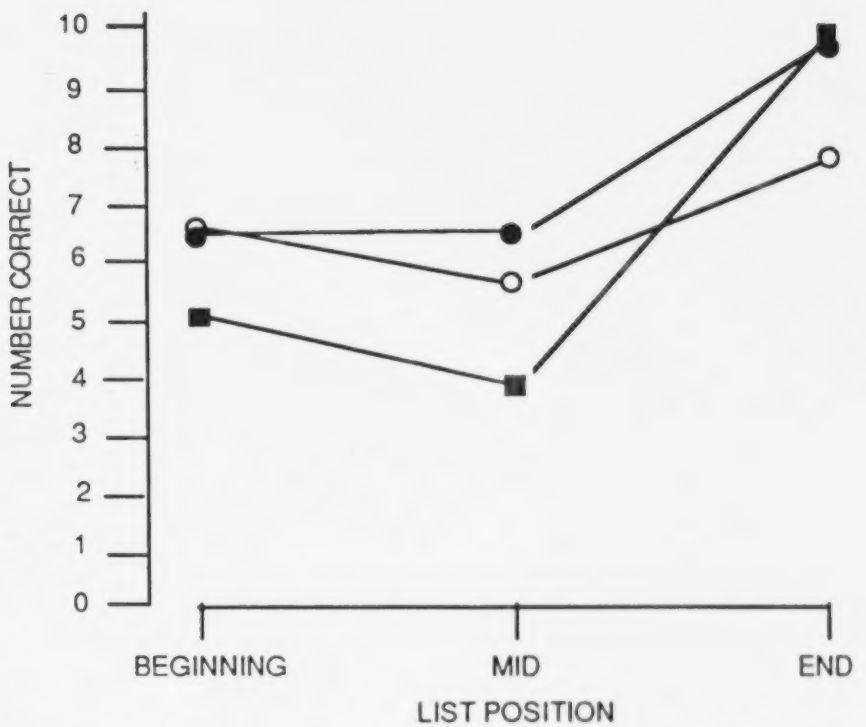
NUMBER CORRECT
10
9
8
7
6
5
4
3
2
1
0
BEGINNING
MID
END
LIST POSITION

Figure 8